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Final Report-Further Development, Support, and Enhancement of CONDUIT

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Introduction

A great deal of progress was made in the past year. Most importantly, the CONDUIT software package was developed to the point where it could be released to several aircraft companies for use in the design of control systems. During the week of February 23 to February 27, 1998, we collaborated with personnel from Moffett Field and California Polytechnic Institute in teaching a short course to 18 representatives of industry and the U. S. Government on the use of CONDUIT. This was a major milestone in the development of CONDUIT. At present, CONDUIT is being used by a number of companies in the design of several aircraft control systems.

Most of our effort during the past year was devoted to research on items for inclusion in the CONDUIT diagnostics menu, work on good illustrative examples of the operation of CONDUIT, and on assisting in publicizing CONDUIT to industry and the government. Substantial progress was made in all of these areas, as will be described in more detail below.

The original goals for this contract are presented in the following section of this report. The modifications to these goals and the reasons for them are also described. This is followed by a section containing the results of work on this contract. A final section contains suggestions for future work on this project.

Original Goals

As implied by the title of this project, the CONDUIT software tool existed when this year's work was begun. The main objectives for this year were to further the development of CONDUIT, enhance CONDUIT, and support the transfer of CONDUIT to industry. Pursuant to these overall objectives, six sub tasks were planned. These sub tasks were

1. Create diagnostics menu
    - Sub task 1.1: Hessians
    - Sub task 1.2: History of Parameter Changes
    - Sub task 1.3: History of Active Constraints
    - Sub task 1.4: Shapes

Sub task 1.5: E-comb

Task 2: Develop collection of examples illustrating the operation of CONDUIT, especially illustrating optimization diseases and their cure.

Task 3: Complete the CONDUIT User's Manual. The draft User's Manual covered only the use of CONDUIT to solve a controller design problem that had already been set up.

Task 4: Fully implement the help menus.

Task 5: Give presentations at Boeing and Sikorsky.

Task 6: Respond immediately to requests from the β-test sites for help, bug notices, changes, and additional features.

Tasks 5 and 6 were completed as planned and according to schedule. A good deal of effort was expended on Task 3. However, we found several problems. First, the development of CONDUIT continued at such a rapid pace during the year that the draft User's Manual was almost continually out of date. Improvements to CONDUIT were constantly requiring major rewrites of the User's Manual. Ultimately, it was decided that it would be better to drop this task and create the User's Manual out of the slides for the CONDUIT Short Course. Thus, we refocussed our documentation efforts to development of materials for the short course.

The original plan had been to use excerpts from the User's Manual as the components of the help menus. Once the decision was made to drop work on the User's Manual there was no point in our continuing with work on the help menus. Work on the help menus was transferred to the personnel at Moffett Field.

Work on Task 2 continued throughout the year. At this time, three tutorial examples have been completed. They are a simple servo loop problem that was used in the CONDUIT Short Course, an F-14 pitch control problem, and an antenna control problem. The F-14 problem is important because it is an IEEE Control System Society benchmark problem. The servo loop problem is documented in [1]. The F-14 and antenna control problems are documented in [2].

Work on Task 1 also took place throughout the year. Once the problem of computing the Hessian was solved we made an important discovery. In most control design problems, CONDUIT finds a solution on a constraint boundary. For such a solution, the Hessian is not usually positive definite. Thus, the diagnostics issue is more complex than we originally thought. This led us to modify the original task slightly. Instead of trying to implement the diagnostics menu it was agreed that it was more important to decide what should be in such a menu first. Thus, emphasis was placed on determining appropriate sensitivity metrics for constrained solutions. This work will be discussed in more detail below.

Results

As was explained above, work on Task 1 led to a modification of the task. Sub tasks 1.1, 1.2, and 1.3 were completed on time. The two histories turned out to be very useful and are currently implemented in CONDUIT. The Hessian computation is sometimes useful but in most cases is not positive definite. This makes most of the metrics associated with the Hessian either poorly defined or confusing. The main reason for the indefinite Hessian is that most control system design problems have their solution on a constraint boundary. The gradients are not zero at such a solution and so the gradient term dominates the Hessian term, making the Hessian somewhat irrelevant. Furthermore, at points that are not near a local minimum the Hessian is typically indefinite. Unlike the identification problem, which was the source of much of our prior intuition, the optimization Hessian is a true second derivative of the performance measure. This need not be positive definite.

We have made substantial progress in clarifying the sensitivity metrics. We have discovered that the Lagrangian of the constrained optimization problem does have a Hessian that is positive definite in a conic region near the optimal solution. We have not had time to explore this idea in greater detail as yet. It is one of the tasks for the present year. Our results on the computation of the Hessian and on the Lagrangian are documented in [2].

As was explained earlier, our results on Task 2 consist of three worked examples. One difficulty that we found in performing this task was that the specifications originally included in CONDUIT were intended for aircraft. Some very standard and useful specifications for servomechanisms are not among the aircraft specifications. We were unable to adapt these aircraft specifications to simple servomechanism problems. Our work along this line led to a deeper understanding of the aircraft specs and the inclusion of several classical servo specs in CONDUIT.

The remaining tasks that were completed as planned consist of housekeeping or publicization. Thus, there are no specific results to report with regard to these tasks. One exception is that a paper describing CONDUIT was presented at the AIAA Guidance, Navigation and Control meeting in New Orleans [3].

Conclusions

The main goal for the year was accomplished. A CONDUIT Short Course was created and taught. Several aircraft companies now have CONDUIT and are using it in the design of aircraft control systems. This is what we have been aiming for since the beginning of this project.

The other major objective for the year was the development of a diagnostic menu for CONDUIT. As often happens in a research project, the first results demonstrated that the goal was premature. We did not, and still do not fully, understand the sensitivity question associated with CONDUIT. We have made substantial progress. We understand the unconstrained sensitivity question completely. We have found a theoretical result that has great promise for the constrained case. We understand the overall question much better than we did. We expect to be able to resolve the parameter sensitivity question fully in the coming year.

References

1. Anon. *CONDUIT—Control Designer's Unified Interface*, Lecture notes from a short course held at the University of Maryland, College Park, MD February 23-27, 1998.

2. Moldoveanu, V. *Case Studies in Computer-Aided Control System Design*, Report (to appear), Institute for Ssytems Research, University of Maryland, College Park, MD, April 1998.

3. Tischler, M. B., Colbourne, J. D., Morel, M. R., Biezad, D. J., Levine, W. S., and Moldoveanu, V., *CONDUIT—A New Multidisciplinary Integration Environment for Flight Control Development,* AIAA Guidance, Navigation and Control Conference, New Orleans, Louisiana, Aug. 11-13, 1997.